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Populus euphratica has stronger regrowth ability than *Populus pruinosa* under salinity stress

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Abstract

Pest infestation and soil salinization levels are increasing due to climate change. Comprehending plant regrowth after insect damage and salinity stress is crucial to understanding climate change's multifactorial impacts on forest ecosystems. This study examined *Populus euphratica* and *P. pruinosa* regrowth after different defoliation levels combined with salinity stress. Specifically, the biomass and regrowth ability, non-structural carbohydrate (NSC) and nitrogen (N) pools in different organs and the whole plant, and the leaf Cl^- concentration of both poplars were analyzed. Our results showed that after 50% defoliation and no salt addition, the regrowth of both species recovered similarly to the control level, while their regrowth was about 70% after 90% defoliation. However, under salinity stress, the regrowth (% leaf biomass) of *P. euphratica* was significantly higher than *P. pruinose* at either the 50% or 90% defoliation levels. Additionally, *P. euphratica* had more soluble sugar, starch, NSC and N pools in leaf, stem, root and whole plant than *P. pruinose* under salinity stress. The regrowth based on leaf biomass increased linearly with soluble sugar, starch, NSC and N pools, and decreased linearly with leaf Cl^- concentration across different salinity and defoliation levels. These results indicated that defoliation significantly decreased NSC and N pools, limiting the growth of both poplars, and salinity stress exacerbated the negative effect. Furthermore, when suffering from salinity stress, *P. euphratica* with higher NSC and N pools exhibited stronger regrowth ability than *P. pruinose*.

1 | INTRODUCTION

The global saline land area was approximately 954 million hectares, increasing by 1–1.5 million hectares annually (Guo et al., 2022; Rao et al., 2008). As a result, many plants are threatened by salinity stress, a global problem that limits plant growth and production and induces huge economic losses (Wei et al., 2020; Zhu, 2016). Moreover, future climate change may result in more aggravated soil salinity (Auler et al., 2021; IPCC, 2022; Wicke et al., 2011), particularly in arid and semi-arid regions. Salinity stress can induce osmotic stress, which may cause plant morphological and physiological responses (Chen et al., 2010; Karst et al., 2017; Wang et al., 2021). In addition, salinity stress usually results in ionic toxicity (e.g., chloride ions), which can reduce the enzymatic reactions, limit proteins and disrupt metabolic processes (Behnke et al., 2013; Polle and Chen, 2015). Thus, salt-exclusion mechanisms that limit root-to-leaf ion transport are critical for plants to cope with salinity stress (Chen and Polle, 2010; Li et al., 2016; Yu et al., 2023). Some species have a morphological adaptation whereby leaves are shed to deal with stresses (Guo et al., 2015; Lambers et al., 2008).

On the other hand, the defoliation caused by herbivores usually harms the growth and production of most plants, and may also be exacerbated by future climate change (Ballina-Gómez et al., 2010; Bouzidi et al., 2019; Huttunen et al., 2007; Kuehne et al., 2014; Zhao et al., 2008). The defoliation directly decreased the photosynthetic leaf area, thus declining the supply of non-structural carbohydrates and limiting growth (Liu et al., 2017; Schmid et al., 2017). However, many perennial plants have adaptive strategies for leaf loss, such as regrowth (e.g., new buds or leaves)(Kosola et al., 2006; Schmid et al., 2017). The

regrowth refers to the process in which, after defoliation, plants activate and regenerate through growth point cells, producing new tissues and leaves for recovery (Ida et al., 2012; Pang et al., 2018). It depends on the nutrient storage in the roots, stems and leaves of plants (Atkinson et al., 2014; Kosola et al., 2006; Pang et al., 2018; Schmid et al., 2017).

Previous studies have found that some plants can recover and even over-regrowth immediately after partial defoliation, resulting in higher biomass and faster growth rate (Striker et al., 2008; Zhao et al., 2008). The reason may be that partial defoliation alleviates water loss, improves leaf water use efficiency, and the regrowth leaves have a higher photosynthetic capacity and stomatal conductance (Dietrich et al., 2018; Khan et al., 2007; Quentin et al., 2012; Striker et al., 2008; Zhang et al., 2021). The mobilization of stored non-structural carbohydrates (NSCs, the sum of soluble sugar and starch) and nutrients is an essential physiological mechanism of defoliation tolerance (Myers and Kitajima, 2007; Palacio et al., 2008). Therefore, plants with higher NSC and N storages may perform better regrowth and adaptation to defoliation (Hoch and Körner, 2003; Piper and Fajardo, 2014).

NSC is closely linked to survival, growth, and recovery from disturbance (Dietze et al., 2014; Galiano et al., 2011; Myers and Kitajima, 2007; Wiley et al., 2013). Soluble sugar provides direct energy for plant growth, defense, osmotic regulation and signaling (Hartmann and Trumbore, 2016; Martínez-Vilalta et al., 2016), while starch serves as a carbon resource that can convert to soluble sugar (Hesse et al., 2021; MacNeill et al., 2017). Previous studies have reported that salinity stress generally increased soluble sugar concentration, which played an important role in osmoregulation (Kannenberg et al., 2018; Yu et al., 2020), while defoliation reduced carbon storage and NSC (Iqbal et al., 2012; Jacquet et al., 2014; Zhang et al., 2021). Despite its significant importance, insufficient data exists regarding the interplay between NSC responses to salinity stress and defoliation.

Populus euphratica and *Populus pruinosa* are the main tree species growing in desert and semi-desert areas in Xinjiang. *P. euphratica* usually grows in river basins along the riverbanks or deserts where water once flowed. However, *P. pruinosa* is mainly distributed in the intersection of the Tarim River and the middle section of the lower reaches of the Keriya River (Shi et al., 2021; Yu et al., 2020, 2022; Zheng et al., 2016). *P. euphratica* spread more widely, while *P. pruinosa* tended to grow in the riparian zone. Lepidopteran species, such as larvae of *Apocheima cinerarius* Erschoff (Geometridae) and *Catocala remissa* Staudinger (Erebidae), are the main insects eating up leaves of the poplar forests of the Tarim Basin, resulting in leaf loss (defoliation)(Schäfer et al., 2017). These infestations usually occur in mid-April, throughout the poplar growth season, resulting in moderate to severe defoliation.

As plants frequently experience diverse stresses and their interactions in natural ecosystems, there is a need to understand better their combinational effects. For exemple, the regrowth of *P. euphratica* and *P. pruinosa* after combined defoliation and salinity stress, two common stresses faced by these species, should be explored. This study aimed to determine the defoliation tolerance of *P. euphratica* and *P. pruinosa* and whether salinity stress affected the regrowth after defoliation. The biomass and regrowth, NSC and N pools in different organs and the whole plants, and Cl^- concentration in leaves of *P. euphratica* and *P. pruinosa* were compared under different defoliation and salinity stress levels. We hypothesized that: (1) Salinity stress limited the regrowth of both poplars after defoliation, (2) *P. euphratica* had a stronger regrowth ability than *P. pruinosa* under salinity stress.

2 | MATERIALS AND METHODS

2.1 | Study site and experimental design

Our experiment was conducted at the gardening station of Tarim University, situated in the northern part of the Taklimakan Desert and the upper reaches of Tarim River (1009 m above sea level, 40°54′ N, 81°30′E). The climate is typical of a temperate desert climate, with an average of 2750–3029 annual sunshine hours, less than 50 mm of rainfall, and over 2500 mm of annual evaporation (Yu et al., 2020, 2022).

In April 2015, we sowed the seeds of *Populus euphratica* and *Populus pruinosa* in a nursery. After more than two years of growth and cultivation, we selected 60 *P. euphratica* and 60 *P. pruinosa* seedlings with approximately uniform size (about 120 cm height). Then, we transplanted them into 30-liter plastic pots (one seedling per pot) with homogenized soil. Soil physicochemical traits with a pH of 8.75 ± 0.04, organic matter content of 26.42 ± 0.74 mg g^{-1}, total nitrogen content of 0.88 ± 0.07 mg g^{-1}, total phosphorus content of 1.12 ± 0.01 mg g^{-1} (Yu et al., 2020). The salinity and defoliation treatments were conducted in April and harvested in late August. Schäfer et al. (2017) reported that insects often defoliated poplars in the Tarim Basin from April to May.

Populus euphratica and *Populus pruinose* with different levels of defoliation and salinity stress were randomly assigned. Thus, we had six treatments with 10 replicates each as follows: control treatment (0% defoliation and no salt), salinity stress treatment (salt addition), 50% defoliation treatment (moderate defoliation), 90% defoliation treatment (severe defoliation), 50% defoliation combined with salinity stress treatment, 90% defoliation combined with salinity stress treatment. Salinity stress was imposed by irrigating with a 100 mM NaCl solution every other day for 5 times during 10 days (Janz et al., 2012). 50% defoliation meant every other leaf was removed, while a 90% defoliation corresponded to almost all leaves removed except for the top two or three leaves to prevent the species from dying under salinity stress.

2.2 | Harvesting and measurements

At the end of our experiment, all plants were harvested and separated into roots, stems, and leaves, dried at 70°C to a constant weight, and then weighed. N concentration was determined using the Kjeldahl method, which oxidizes amino nitrogen to nitrate and then titrates to produce nitrite (Mitchell, 1998). Soluble sugar concentration was determined by the anthrone method using the supernatant after dissolving 0.05 g of dry sample in 80% ethanol followed by repeated water baths and centrifugation. Starch concentration was determined by extracting the supernatant from the dried residue using 9.2 M and 4.6 M perchloric acid solutions (Landhäusser et al., 2018; Quentin

et al., 2015; Song et al., 2017). Cl^- concentration was measured using the silver nitrate titration method (Chen et al., 2001). Yu et al. (2020) have provided additional details on the methodology used.

2.3 | Data analysis

The regrowth after defoliation (e.g., 50% and 90%) was defined as the percentage of leaf biomass harvested at the end of the experiment relative to the initial leaf biomass, respectively (Piper and Fajardo, 2014), and the formula as follows:

$$Re = (l_h - l_i) * 100/l_i$$

Where *Re* indicates regrowth, l_h indicates total leaf biomass harvested at the end of the experiment, and l_i is the initial leaf biomass.

For determining the NSC or N pools for each organ, the organ N pool was calculated by multiplying the organ N concentration by organ biomass, and then the whole plant N pool was the sum of the leaf, stem and root N pools (Yu et al., 2019). Same was done for NSC.

All data were checked for normality and the homogeneity of variances test, and log-transformed to correct deviations from the assumptions when necessary. The significance of differences between treatments was assessed using Tukey's test. Independent-sample t-tests were used to determine the differences between *P. euphratica* and *P. pruinosa*. All statistical effects were considered significant when $P < 0.05$. In addition, simple linear regressions were conducted to assess the relationships between regrowth and NSC, N pool, and leaf Cl^- concentration. Regression analysis between different variables was performed using SigmaPlot 12.5 (Systat Software Inc.). Statistical analyses were conducted using the Windows Statistical Package for the Social Sciences (SPSS, Inc.). Pearson's correlation analysis was conducted on various measured traits of the whole plant using R 4.3.2 software and RStudio (r package "corrplot", Visualization of a Correlation Matrix, Version 0.92 for Windows) to assess the pairwise relationships among them.

3 | RESULTS

3.1 | Plant biomass and regrowth

Compared with the control treatment, salinity stress and defoliation have significantly decreased the biomass of both poplars ($P < 0.05$, Figure S1). Under salinity stress, *P. euphratica* exhibited higher leaf, root and total biomass than *P. pruinose*, regardless of leaf removal (Figure S1). In addition, both poplars showed limited regrowth after defoliation when exposed to salinity stress, and *P. euphratica* had higher regrowth than *P. pruinose* under the combined salinity stress and defoliation ($P < 0.05$, Figure 1). For example, both species with 50% defoliation could regrow (% leaf biomass) to the control level (no defoliation) when no salt was added. In the presence of salinity stress and 50% defoliation, the regrowth of *P. euphratica* and *P. pruinose* was 60.98% and 36.59%, respectively. However, under even more stressful conditions, with salinity stress and 90% defoliation,

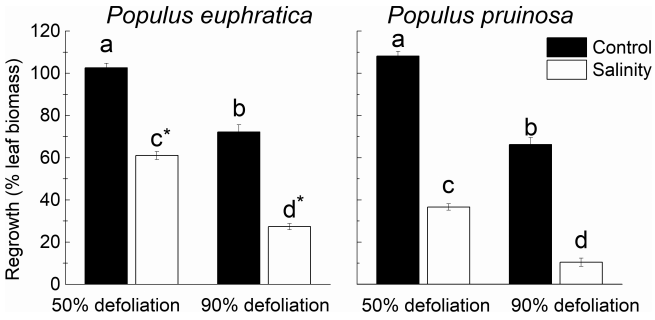

FIGURE 1 Regrowth based on leaf biomass in *P. euphratica* and *P. pruinosa* under different defoliation and salinity levels. Each value is the mean ± SE ($n = 5$). The black bars indicate no salt, and the white bars indicate added salt treatments. Different letters above bars denote significant differences according to Tukey's test at a significance level of $P < 0.05$. * indicates significant differences between *P. euphratica* and *P. pruinosa* within treatment according to a *t*-test at a significance level of $P < 0.05$.

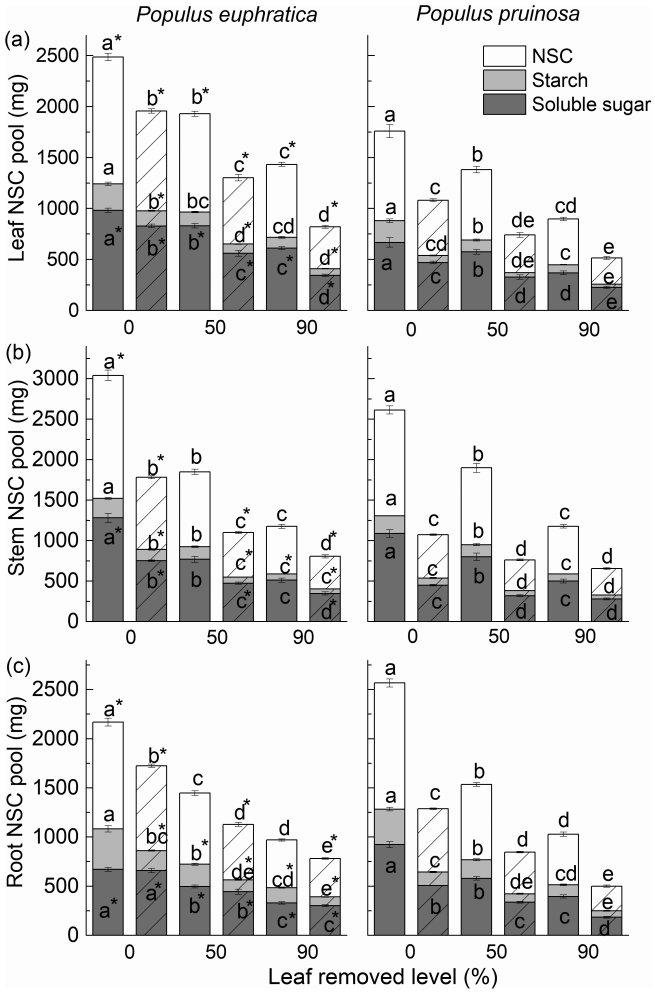

FIGURE 2 NSC pool of (a) leaf, (b) stem, and (c) root in *P. euphratica* and *P. pruinosa* under different defoliation and salinity levels. Each value is the mean ± SE ($n = 5$). Slashed lines represent the response under salinity stress. Different letters above bars denote significant differences according to Tukey's test at a significance level of $P < 0.05$. *denotes significant differences between *P. euphratica* and *P. pruinosa* within treatment according to a *t*-test at a significance level of $P < 0.05$.

the regrowth of *P. euphratica* and *P. pruinose* was 27.33% and 10.41%, respectively (Figure 1).

3.2 | NSC and N storages

Leaf removal resulted in a significant increase in N concentration in leaves of *P. euphratica* and *P. pruinose*, but a significant decrease in N concentration in stems and roots, especially in salinity stress and defoliation conditions ($P < 0.05$, Figure S2). Furthermore, after defoliation, the leaf NSC concentration of *P. euphratica* was significantly higher than *P. pruinose* ($P < 0.05$, Figure S3). In addition, both salinity stress and defoliation significantly decreased NSC and N pools in different organs and the whole plant of both poplars compared to the control treatment ($P < 0.05$, Figures 2, 3, S4 and S5). Without salinity stress, the soluble sugar, starch, NSC, and N pools of the whole plant were similar between *P. euphratica* and *P. pruinose*, regardless of the leaves

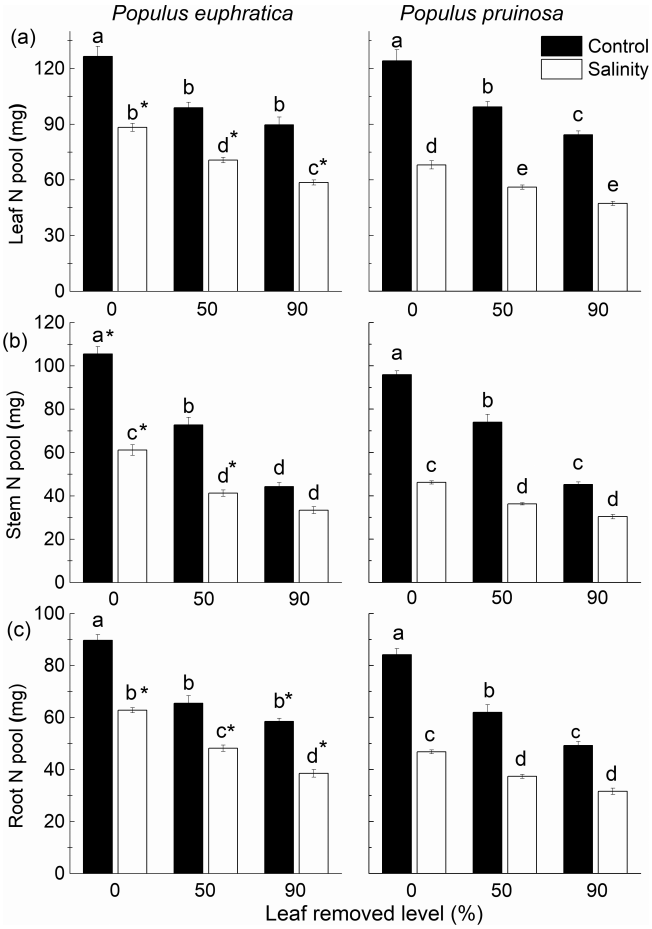

FIGURE 3 (a) Leaf N pool, (b) stem N pool, and (c) root N pool in *P. euphratica* and *P. pruinosa* under different defoliation and salinity levels. Each value is the mean ± SE ($n = 5$). The black bars represent no salt, and the white bars added salt treatments. Different letters above bars denote significant differences according to Tukey's test at a significance level of $P < 0.05$. *denotes significant differences between *P. euphratica* and *P. pruinosa* within treatment according to a *t*-test at a significance level of $P < 0.05$.

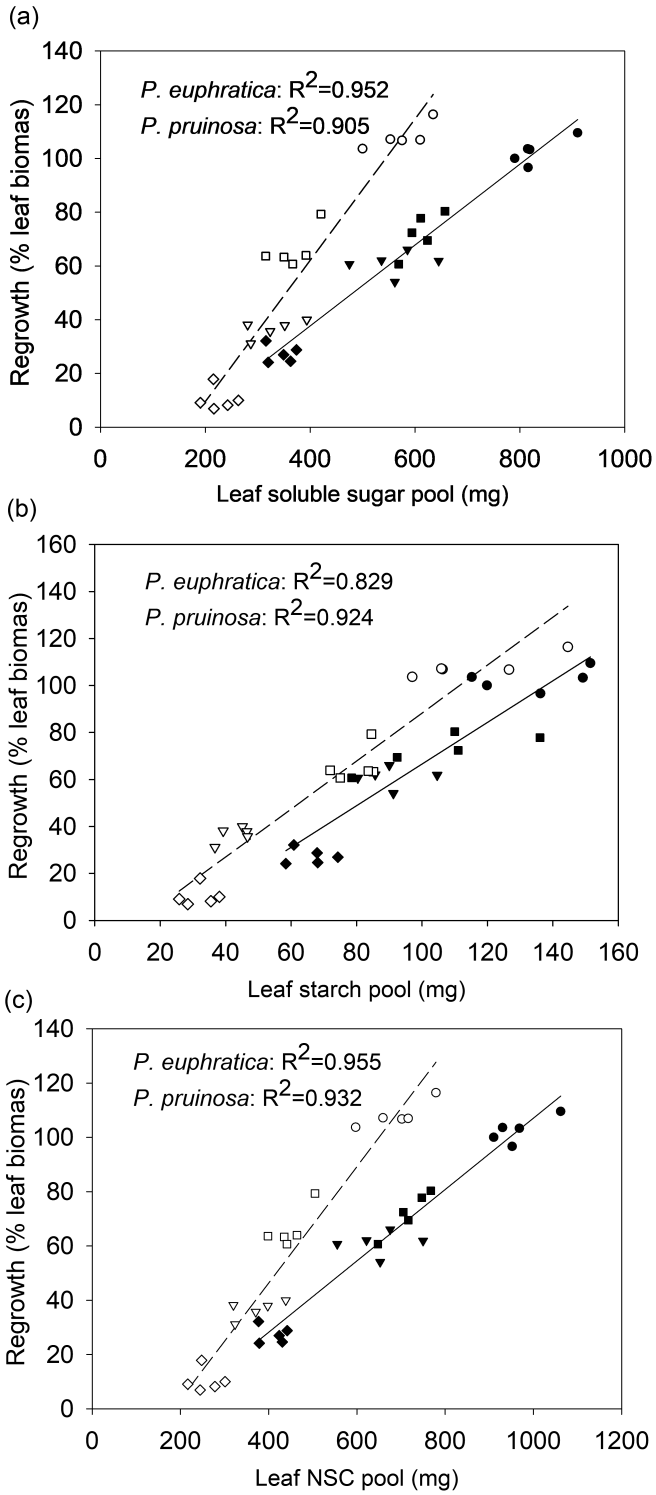

FIGURE 4 Relationships of regrowth based on leaf biomass with leaf soluble sugar pool (a), leaf starch pool (b) and leaf NSC pool (c) in *P. euphratica* and *P. pruinosa* across different defoliation and salinity levels. The white circle, square, triangle, and diamond indicate *P. pruinosa* under 50% defoliation, 90% defoliation, 50% defoliation with salinity stress, and 90% defoliation with salinity stress, respectively. The black circle, square, triangle, and diamond indicate *P. euphratica* under 50% defoliation, 90% defoliation, 50% defoliation with salinity stress, and 90% defoliation with salinity stress, respectively.

removed. However, under salinity stress, *P. euphratica* exhibited higher soluble sugar, starch, NSC and N pools in different organs and whole plant than *P. pruinose* ($P < 0.05$, Figures 2, 3, S4 and S5).

3.3 | Correlations between regrowth and NSC, N pools and leaf Cl^- concentration

The regrowth based on leaf biomass increased linearly with leaf and whole plant soluble sugar, starch, NSC and N pools ($P < 0.05$, Figures 4,5 and S6), whereas it decreased linearly with leaf Cl^- concentration across different salinity and defoliation levels ($P < 0.05$, Figure 6).

For both poplars, leaf regrowth based on biomass showed significant positive correlations with different organs and whole plant soluble sugar, starch, NSC and N concentrations and pools ($P < 0.05$, Figure 7), except root soluble sugar and NSC concentrations in *P. euphratica*, whereas it decreased linearly with leaf Cl^- concentration across different salinity and defoliation levels ($P < 0.05$, Figure 7). A conceptual diagram representing the main studied parameters in *P. pruinose* and *P. euphratica* across different defoliation and salinity levels (Figure 8).

4 | DISCUSSION

4.1 | The combined effects of salinity and defoliation on biomass and regrowth

Defoliation usually decreases photosynthetic leaf area and significantly reduces plant growth and biomass accumulation (Liu et al., 2017; Schmid et al., 2017; Wang et al., 2021). Additionally, defoliation can alter hormonal levels and growth regulators, potentially impacting plant growth (Lilley et al., 2012; Wiley et al., 2013). Our results indicate that defoliation significantly reduced leaf, stem, root, and whole-plant biomass of both poplars, which is consistent with previous reports. Moreover, the negative effects of defoliation were amplified by salinity stress, resulting in a substantial reduction in the biomass of various organs or the whole plant

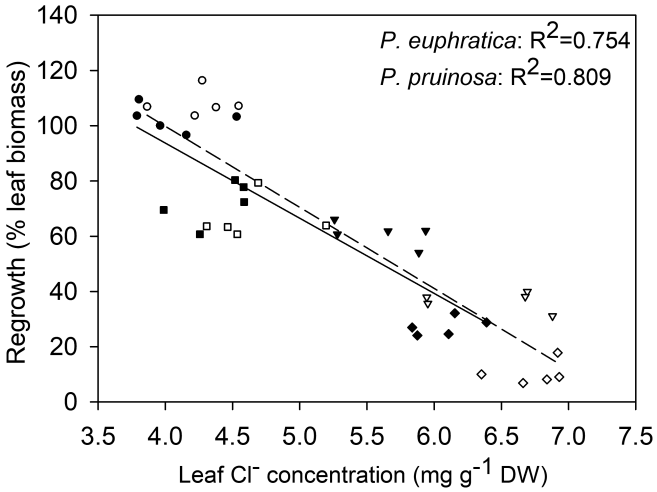

FIGURE 6 Relationships of regrowth based on leaf biomass with leaf Cl^- concentration in *P. euphratica* and *P. pruinosa* across different defoliation and salinity levels. The white circle, square, triangle, and diamond indicate *P. pruinosa* under 50% defoliation, 90% defoliation, 50% defoliation with salinity stress, and 90% defoliation with salinity stress, respectively. The black circle, square, triangle, and diamond indicate *P. euphratica* under 50% defoliation, 90% defoliation, 50% defoliation with salinity stress, and 90% defoliation with salinity stress, respectively.

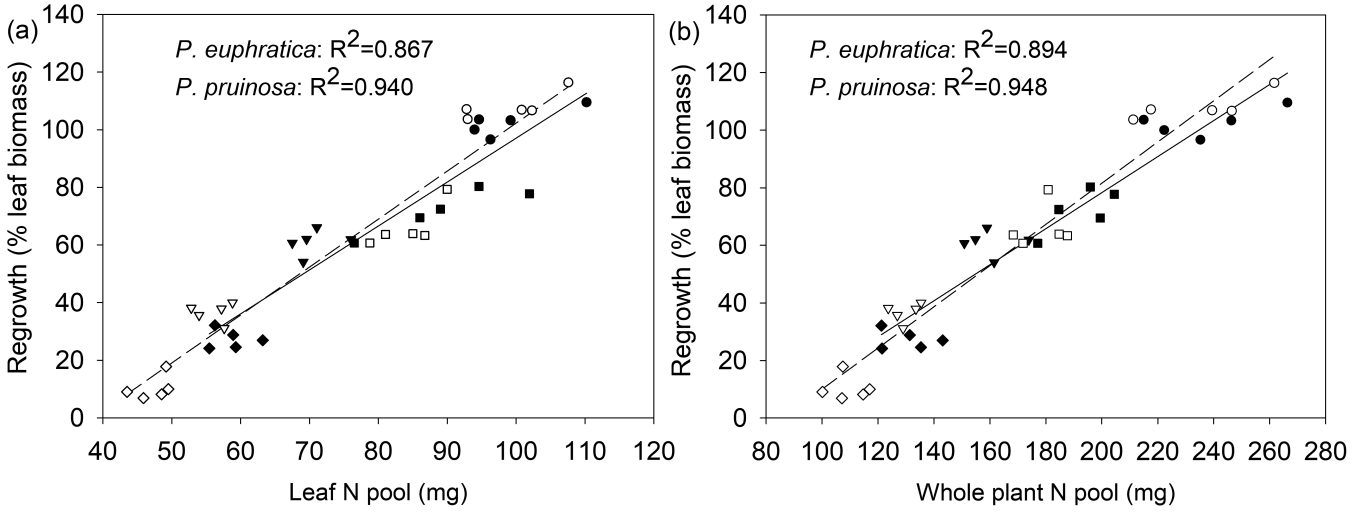

FIGURE 5 Relationships of regrowth based on leaf biomass with (a) leaf N pool and (b) whole plant N pool in *P. euphratica* and *P. pruinosa* across different defoliation and salinity levels. The white circle, square, triangle, and diamond indicate *P. pruinosa* under 50% defoliation, 90% defoliation, 50% defoliation with salinity stress, and 90% defoliation with salinity stress, respectively. The black circle, square, triangle, and diamond indicate *P. euphratica* under 50% defoliation, 90% defoliation, 50% defoliation with salinity stress, and 90% defoliation with salinity stress, respectively.

(Figure 1). Furthermore, when exposed to salinity stress, *P. euphratica* showed greater tolerance than *P. pruinose*, as demonstrated by less reduction in leaf, root and whole plant biomass across different defoliation levels (Yu et al., 2020).

Previous studies have reported that several infestations of poplars in the Tarim Basin by Lepidopteran species occur frequently from mid-April to May, resulting in moderate to complete defoliation (Schäfer et al., 2017; Zheng et al., 2014). Our study first compares the regrowth of two desert poplars after defoliation under salinity stress. We found that when salt was not present, after experiencing 50% defoliation, both species displayed comparable levels of regrowth to the control level (Figure 1). Meanwhile, after 90% defoliation, the regrowth of both species reached about 70% of the control level (Figure 1). These findings highlight poplars' strong regrowth ability, as suggested by a former study (Schäfer et al., 2017). These results were consistent with previous studies showing that moderate defoliation had a higher regrowth ability than severe defoliation, indicating that high-intensity defoliation leads to slow recovery and regrowth (Piper and Fajardo, 2014; Wiley et al., 2013). Additionally, when exposed to salinity stress, *P. euphratica* and *P. pruinose* had distinct regrowth (% leaf biomass) abilities after defoliation ($P < 0.05$). Under 50% defoliation, *P. euphratica* had a regrowth of 60.98%, while *P. pruinose* had a regrowth of 36.59%. When defoliated by 90%, *P. euphratica* had a regrowth of 27.33%, and *P. pruinose* had a regrowth of 10.41%. These results indicated species-specific regrowth responses to salinity stress, and *P. euphratica* exhibited higher regrowth ability under salinity stress.

4.2 | NSC and N storages

Defoliation generally resulted in a net loss of stored NSC and decreased C fixation due to the declined photosynthetic area (Jacquet et al., 2014; Li et al., 2002). Previous studies have demonstrated that plants can maintain and recover NSC levels after defoliation (Jacquet et al., 2014; Palacio et al., 2008, 2012). Under moderate defoliation, leaf NSC concentrations of both poplars remained similar to the control treatments, whereas NSC concentrations in stems and roots were decreased (Figure 6). This finding suggests that both poplars showed a strong mobilization of C storages from stems and roots to leaf tissues, likely to satisfy the carbon demands exaggerated by decreased photosynthetic capacity (Wiley et al., 2013). However, severe defoliation reduced NSC concentrations and pools in all plant organs, leading to C limitation on growth (Elise and Jason, 2020; Ida et al., 2012; Li et al., 2002; Piper and Fajardo, 2014; Wiley et al., 2013). Additionally, defoliated plants displayed maintained or even increased leaf N

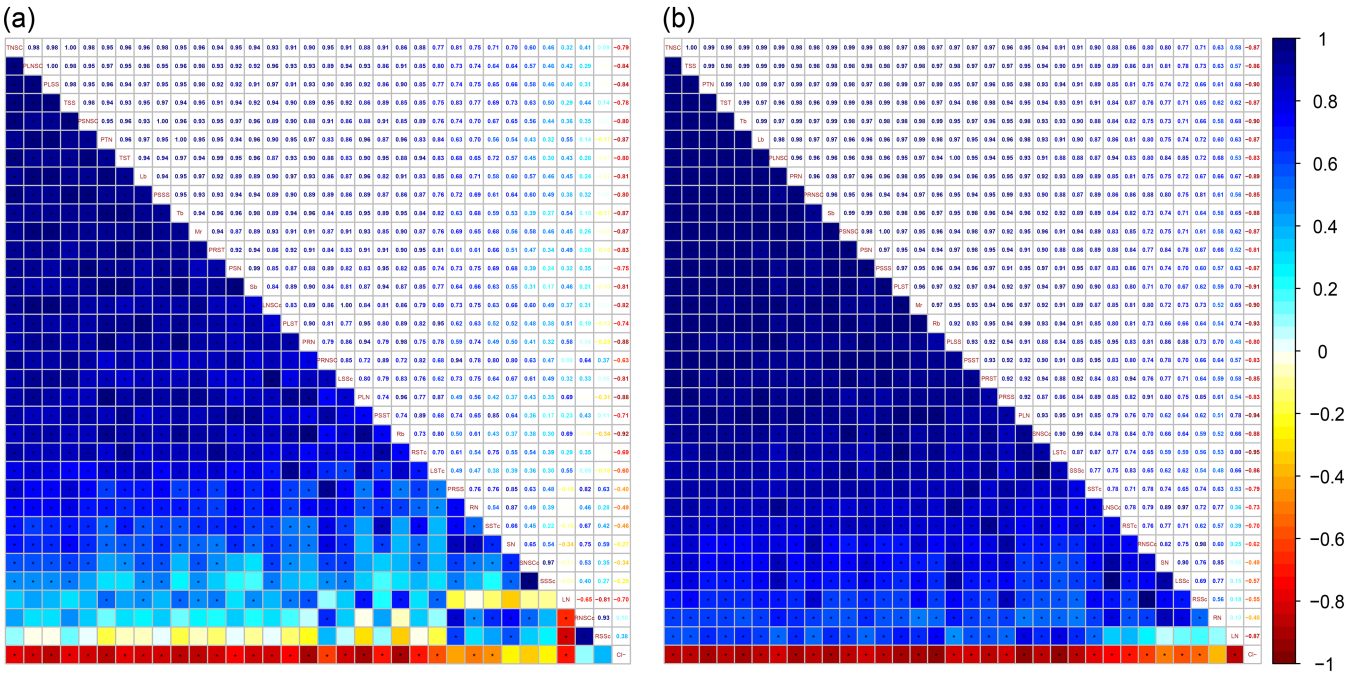

FIGURE 7 Pearson's correlation analysis of all measured traits: (a) *P. euphratica*; (b) *P. pruinosa*. Correlation coefficient increases with color; significance level $p < 0.05$. Abbreviations: Tb, total biomass; Lb, leaf biomass; Sb, stem biomass; Rb, root biomass; TNSC, whole plant NSC pool; TSS, whole plant soluble sugar pool; TST, whole plant starch pool; PLNSC, leaf NSC pool; PSNSC, stem NSC pool; PRNSC, root NSC pool; PLSS, leaf soluble sugar pool; PSSS, stem soluble sugar pool; PRSS, root soluble sugar pool; PLST, leaf starch pool; PSST, stem starch pool; PRST, root starch pool; LNSCc, concentration of leaf NSC; SNSCc, concentration of stem NSC; RNSCc, concentration of root NSC; LSSc, concentration of leaf soluble sugar; SSSc, concentration of stem soluble sugar; RSSc, concentration of root soluble sugar; LSTc, concentration of leaf starch; SSTc, concentration of stem starch; RSTc, concentration of root starch; PTN, whole plant N pool; PLN, leaf N pool; PSN, stem N pool; PRN, root N pool; LN, concentration of leaf N; SN, concentration of stem N; RN, concentration of root N; Mr, leaf regrowth biomass; Cl^-, concentration of leaf Cl^-.

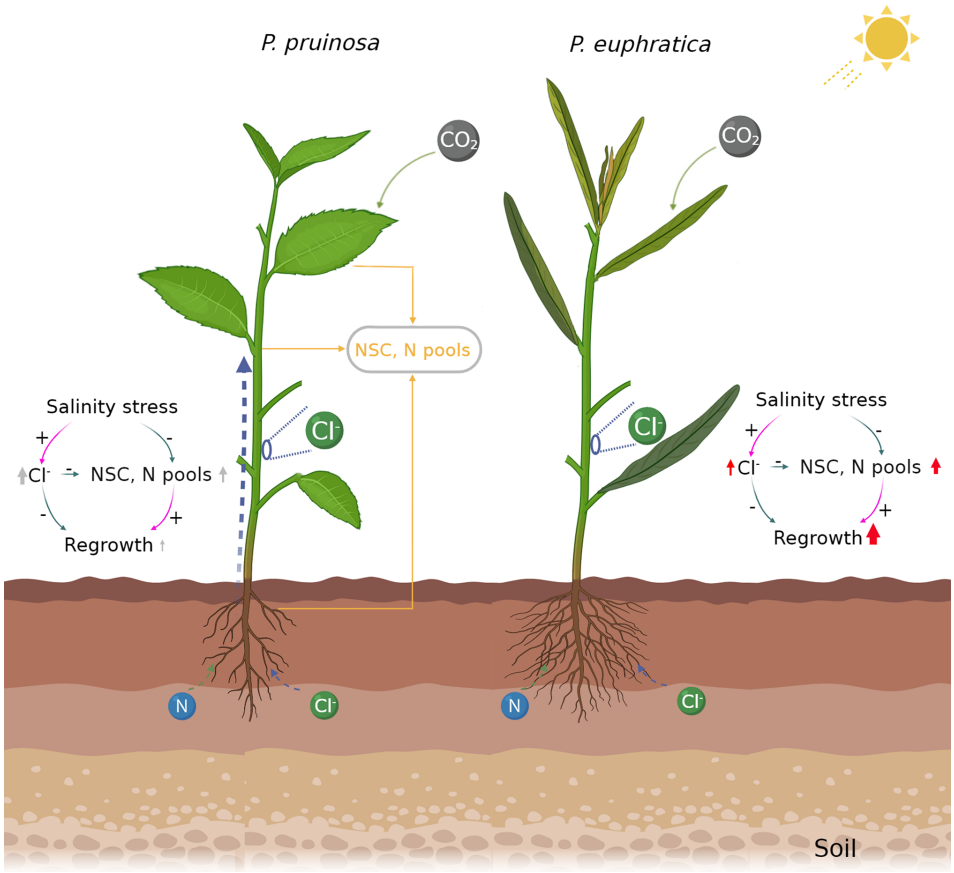

FIGURE 8 Conceptual diagram representing the main studied parameters in *P. pruinose* and *P. euphratica* across different defoliation and salinity levels. "+" and "−" indicate positive and negative effects, respectively. The size of arrows denotes the levels of effect.

concentration, accompanied by decreased N concentration in their stems and roots (Figure 7), suggesting N mobilization and redistribution within the plant, potentially leading to N deficiency (Jacquet et al., 2014).

On the other hand, defoliation significantly decreased NSC and N pools throughout the plant, with severe defoliation resulting in the depletion of C and N storages. In addition, *P. euphratica* and *P. pruinose* had comparable NSC and N pools in each organ and the whole plant without salinity stress (Figures 2-5). However, *P. euphratica* exhibited higher NSC and N storages than *P. pruinose* under salinity stress, likely due to its stronger resistance to salinity stress, higher biomass, greater photosynthetic capacity (Yu et al., 2020). Previous studies have demonstrated that higher C and N storages in plants correlate with better growth and performance (Elise and Jason, 2020; Ida et al., 2012; Jordan et al., 2014; Merryn et al., 2018; Piper and Fajardo, 2014; Uhde-Stone et al., 2003). Our results support those studies, suggesting a positive linear correlation between regrowth (based on leaf biomass) and levels of soluble sugar, starch, NSC and N pools in both leaves and whole plant (Figures S1-S3), but a negative linear correlation with Cl^- concentration of leaves (Figure S4). Our results also demonstrated that *P. euphratica* displayed a more robust regrowth response and was closely related to NSC and N storages under salinity stress conditions. Previous studies have reported that seedlings are more sensitive than large trees, and they are different in growth rate, photosynthetic capacity and NSC concentrations and pools (Thomas et al. 2002; Hartmann et al. 2018; Zhang et al. 2020). Additionally, all natural systems interact with their surroundings and are subject to multi-disturbance. For instance, seedlings usually suffer lower light irradiation and limited roots in shallower soil layers compared with large trees (Cavender-Bares and Bazzaz, 2000; Oberhuber et al., 2015). Thus, seedlings and large trees may differ in their regrowth strategy and a long-term field experiment is needed to investigate regrowth in the natural systems.

CONCLUSION

The present study revealed that defoliation significantly decreased NSC and N pools, limiting the growth of *P. euphratica* and *P. pruinose*, and salinity stress exacerbated this negative effect. When exposed to salinity stress and 50% defoliation, the regrowth (% leaf biomass) of *P. euphratica* and *P. pruinose* were 60.98% and 36.59%, respectively. Similarly, under salinity stress and 90% defoliation, *P. euphratica* and *P. pruinose* had a regrowth of 27.33% and 10.41%, respectively. Besides, the regrowth of both species showed a positive correlation with the levels of soluble sugar, starch, NSC and N pools in both leaves and the whole plant. In contrast, it decreased linearly with leaf Cl^- concentration across different salinity and defoliation levels. These findings demonstrated that *P. euphratica* had stronger regrowth and was closely related to NSC and N storages under salinity stress.

Considering the increasing insect damage and soil salinization levels under climate change, it is crucial to understand the regrowth and defoliation tolerances of *P. euphratica* and *P. pruinosa* for ecological protection and afforestation in arid regions.

AUTHOR CONTRIBUTIONS

Zongdi Huang was mainly responsible for data collection, analysis and writing, Juntuan Zhai and Zhijun Li contributed to data analysis, and Lei Yu (the corresponding author) was responsible for experimental design and project management.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

All relevant datasets for this study can be reasonably requested from the corresponding authors.

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